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STRATEGIC NUTRIENT MANAGEMENT OF FIELD PEA IN SOUTHWESTERN UGANDA

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ABSTRACT

The highlands of southwestern Uganda account for the bulk of field pea (*Pisum sativum* L.) produced and consumed in the country. The crop fetches a stable price, which is as high as that of beef, but it has remained outside the mainstream of the research process. Low soil fertility, unfortunately, is poised to eliminate the crop. Nitrogen, phosphorus and potassium have variously been reported as deficient on the bench terraces where crop production is primarily done. Strategic nutrient management requires that the most limiting nutrient is known in order to provide a foundation for designing effective and sustainable soil fertility management interventions. A study was conducted on upper and lower parts of the bench terraces on the highlands in south-western Uganda to identify the most required macro-nutrient(s) in field pea production. Treatments included: 0 and 25 kg N ha^{-1}, 0 and 60 kg P ha^{-1}, and 0 and 60 kg K ha^{-1}, all applied factorially in a randomized complete block design. Parameters assessed included nodulation, nodule effectiveness for BNF and dry weight, shoot dry weight, and grain yield. Nutrient applications that resulted in the highest crop responses were considered as most required, and hence, most limiting to plant growth and yield. Phosphorus based nutrient combinations gave the highest increments in total and effective nodule numbers, as well as dry weight, irrespective of terrace position. On the other hand, N based combinations led to the highest shoot dry matter at flowering (39 % higher over the control). The superiority of N was carried over up to final harvesting, with stover and grain yields edging out the other treatment regimes on either terrace positions. Phosphorus was most limiting nutrient, though the effect manifested in terms of the intensity of BNF indicators, followed by nitrogen, that manifested at later stages of crop growth influencing stover and grain yield.

Key words: Nutrients, nodulation, biomass, grain yield

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INTRODUCTION

Field pea (*Pisum sativum* L*)* is a legume crop, reportedly among the key components of human diets worldwide [1]. It is cultivated for fresh green seed, tender green pods, dried seed and forage. In sub-Saharan Africa (SSA), field pea is a primary source of protein for many communities, in spite of the fact that it is hitherto largely understudied among legume crops. It is commonly grown in the cool highlands of Africa like in Ethiopia and Kenya.

In Uganda, field pea is a staple as well as a major income earner for most small-scale farmers in the highlands of southwestern (SW) region, where the agro-ecology is most suited for its production. The crop fetches a stable price, which is as high per kilogram as that of beef, yet it has remained outside the mainstream of the research process [2, 3, 4]. Apart from the local demand which is far from satisfaction, the crop presents great potential for export to European countries where it is heavily consumed and forms a significant component of the diets and yet the local supply in Uganda is still fairly low.

The crop is traditionally grown rotation with other crops on terrace benches constructed on the steep hills of SW Uganda. These terraces have been continuously cropped for decades without nutrient management attention; hence soil fertility depletion is among the major factors constraining field pea and crop production in general in this region [2]. In fact, on-farm yields currently stand at a paltry 400 kg ha^{-1}, contrasting with 2 t ha^{-1} obtained in other countries [5]. Literature on soil fertility management is still hard to trace in the entire eastern Africa.

Field pea is a renowned heavy consumer of N and P [6]. Although as a legume, the crop is endowed with potential for replenishing soil N through biological N fixation (BNF), the continuous production process results in depletion of the other nutrients, especially P and K which are required in fairly large quantities by the crop. Besides, the viable performance of BNF depends on the adequacy and balanced proportions of the spectrum of the other nutrients [7].

In order to elevate the productivity of field pea to profitable levels in Uganda, it is prudent that renewed attention is focused on sustainable soil fertility management. The objective of this study, therefore, was to identify the most limiting nutrient to production of the crop as the strategic entry point to effective management and subsequent formulation of rationalized packages.

MATERIALS AND METHODS

An on-farm experiment was conducted on bench terraces of SW Uganda, in Kabale district during two rainy seasons of 2005 (September-December) and 2006 (March-July) (Plate 1). The area is characterised by a mountainous relief of flat topped hills and ridges, underlain by partly granitised and metamorphosed Precambrian rock formations of the Karagwe–Ankolean system [8]. Elevation ranges between 1,300 and

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2,400 m above sea level, with bi-modal annual rainfall pattern. The annual minimum and maximum means are 1,092 and 1500 mm, respectively, while respective temperatures are 10 and 23 ^{o}C [9]. In general, the soils of the region were identified as Ferralsols [10].

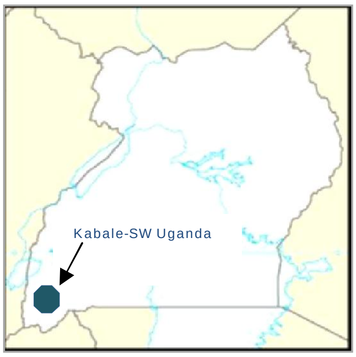

Plate 1: Study area in SW Uganda

The study involved ten farm fields and these were in effect the replications. Treatments included two terrace positions, namely upper (UTP) and lower (LTP); N, P and K applied as 0 and 25 kg N ha^{-1}, 0 and 60 kg P ha^{-1}, and 0 and 60 kg K ha^{-1}. The experiment was factorial and was laid out in a randomized complete block design. Nitrogen, P and K were applied in the form of urea, triple super phosphate and muriate of potash (KCl), respectively. Choice of the rates was based recommendations for a number of annual legumes in the country [11].

The experimental sites' soil (0-20 cm depth) was pre-analysed for pH (water), total N and organic matter content, available P, and exchangeable K^{+} and Ca^{2+} using procedures outlined by [12]. A locally known field pea variety which is "white and black eyed" called *Meisho* was used. Because available stockists did not carry certified field pea seed, farmers' stocks off the previous season were used. As such, seed viability was tested using routine procedures. In plots of 4 m by 4 m, seeds were planted by broadcasting and incorporated into soil. The experiment was entirely rain-fed, and was managed following farmer practices.

Parameters assessed included nodulation, nodule effectiveness for BNF and dry weight, shoot dry weight (SDW), and grain yield. Nodule and other associated evaluations were done 30 days after planting (DAP). For this purpose, 10 pea plants were randomly selected from each plot for destructive sampling. They were carefully dug out and the roots freed of adhering soil and debris using distilled water, prior to the evaluation. Nodules were removed, counted and sliced cross-sectionally for assessment for potential BNF using the leghaemoglobin pigment indicator Thereafter, each sample's nodules gravimetric moisture content and eventual dry nodule dry weight was determined. The process involved oven-drying at 65 ^{o}C for 48 hours prior to dry weight determination. All nodule data were expressed per plant as the unit. Immediately after nodule removal**,** the shoots were severed from the roots with a knife, bulked per sample and subjected to gravimetric moisture dry weight determination as described above.

At approximately 60 % flowering, 10 plants were again randomly collected from each plot for further shoot dry weight (SDW) assessment using the gravimetric procedure. Finally, at physiological maturity (120 DAP for this variety), the remaining plants were uprooted, and root parts severed from the shoots with a knife. Fresh weight of the shoots with pods was recorded per plot before ten plants with seed were sub-sampled for dry weight assessment. The remaining plants of the harvested sample were air-dried to 14% moisture content, threshed and winnowed. The clean seeds were weighed and a portion sub-sampled for gravimetric moisture content seed dry weight determination.

Seed yield values were extrapolated to yield per hectare prior to statistical analysis using analysis of variance (ANOVA) using GenStat. Significant treatment means were separated using Fisher's Least Significant Difference (LSD) test at 5 % probability level.

RESULTS

Site soil characteristics Soil pH was generally below the limit of 5.5 (Table 1) widely considered optimal agronomically [12]. On the other hand, total organic matter and exchangeable bases (K^+ and Ca^{2+}) were in the adequate range, total N and plant available P were marginally adequate and critically low, respectively (Table 1). In fact, total N, soil organic matter, and exchangeable bases concentrations varied across the terrace, with higher concentrations in LPT than UPT.

Nodulation and associated parameters Phosphorus based treatment outstandingly ($p<0.05$) increased nodule number and weight (Figures 1 & 2). Application of P alone resulted in a nodule number increment of 54 % over the control (no application), while application of N+P+K and P+K increased the numbers by 53 and 49 %, respectively (Figure 1). Furthermore, the highest increment in nodule weight of 66 % was realised with P alone, followed by P+K with an increase of 62 % (Figure 2). On the other hand, sole application of N and K had no significant effect ($p>0.05$).

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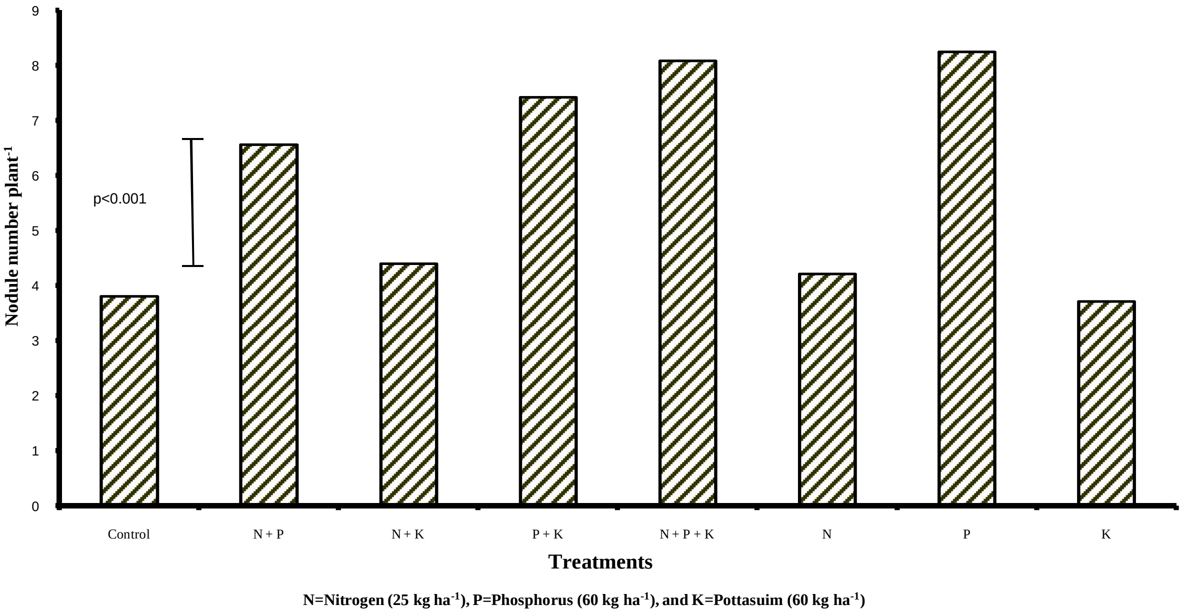

Figure 1: Nutrient application effects on total nodule number in field pea in SW Uganda

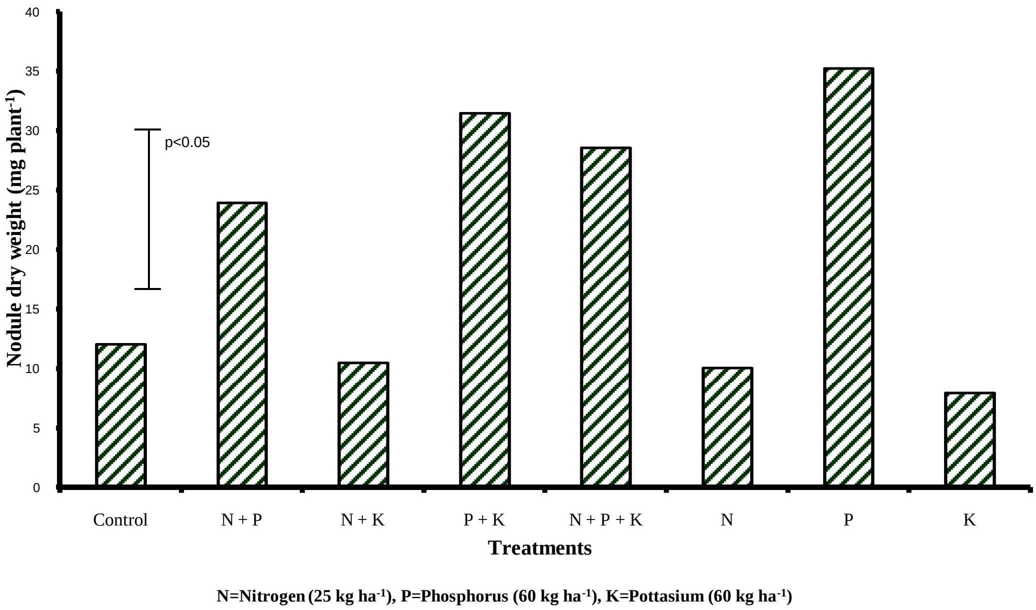

Figure 2: Nutrient application effects on nodule dry weight in field pea in SW Uganda

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Shoot dry matter at 60 % flowering. Shoot dry weight (SDW) response was at variance with the nodule parameters discussed above (Figure 3). In this case, it was the N based treatments that led to the highest SDW over the control. Generally, P and K based combinations trailed. Furthermore, plant sensitivity to the treatments was way superior on the UPT to that of the LPT, with SDW values several fold greater ($p<0.05$). In fact, on the LPT, only N resulted in significant increment in this parameter (Table 2).

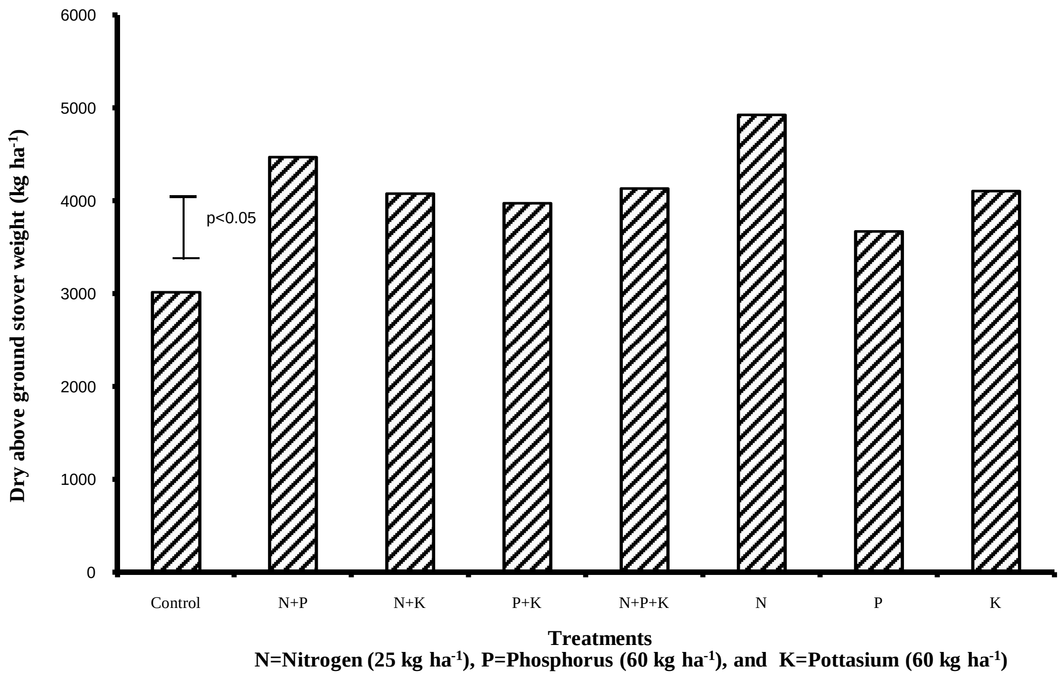

Figure 3: Nutrient application effects on shoot dry weight at flowering in SW Uganda

Stover and grain yield Stover and grain yield at harvest were not significantly ($p>0.05$) influenced by nutrient application within each terrace position though the LTP generally registered significantly ($p>0.05$) higher stover dry weight (3,906 kg ha^{-1}) than its UTP counterpart (3,318 kg ha^{-1}). However, grain yield gave totally contrasting performance, with the upper part of terrace significantly ($p<0.01$) higher (958 kg ha^{-1}) than the lower part (730 kg ha^{-1}).

DISCUSSION

The status of soil in the study site is in conformity with a study done a decade ago [4]. Phosphorus values in the range of 3-7 folds less than the critical limit are suggestive that the element has great potential for limiting plant growth. Research work, earlier done, reported negative effects of sub-optimal soil P supply on field pea performance [4, 13]. On the other hand, the spatial gradient in soil chemical properties across the terraces suggests that soil management within the terrace ought to be disaggregated

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accordingly in order to achieve realistic crop responses. However, how management of such micro-site level resource variations fits into the small-scale farmers' biophysical and socio-economic frameworks needs further investigation.

This sequence of observations on nodule parameters demonstrates that phosphorus was most required nutrient relative to N and K. Phosphorus plays a key role in nodule activity through increased formation and availability of Adenosine Tri-phoshosphate (ATP), a resource material for the energy intensive for the N reduction process via nitrogenase enzyme activity [14]. In fact, this was evident in the P applied cases where the number of potentially BNF-effective nodules was the highest. Surprisingly, there were a few nodules in the control treatment with the pigment indicative of BNF effective at such low available P concentrations levels. This could be explained by the possibility that the plant has evolved mechanisms for P access at such low levels. A possible candidate mechanism in this case is mychorrhyzae formations which are known to enhance the plant's ability to access the higher plant's access to otherwise unavailable soil resources [15]. This speculation requires an independent investigation. Thus, inclusion of legumes into existing cropping systems seem to have the potential to reduce or eliminate inorganic N fertilization due to their ability to fix N from the atmosphere. Presence of efficient rhizobial strains in highlands is an added opportunity for small-scale farmers in improving grain yields. With most soils in Uganda deficient of P, use of mineral P in such legume crops is a promising intervention for poor resource farmers.

At later growth stages, the disappearance of the outstanding effect of P application on the crop and the emerging superior effect of N, suggest that the latter became limiting in the later stages of plant growth. This could be explained by the fact that the rate of N applied (25 kg ha^{-1}) was rather too low to support the crop through its requirement. A study done elsewhere indicated that high field pea yield responded only at rates as high as 60 kg N ha^{-1} [16]. The observation also implies that the observed soil test total N (Table 1) did not mineralize adequately to influence plant available N concentrations to sufficiently supplement applied N. This suggests that soil total N is not a dependable index for soil N availability to a crop. Furthermore, the emergent superior influence of N implies that biologically fixed N by the crop was equally inadequate to additionally cater for the crop needs. At this stage, this study has demonstrated that P and N are closely related as limiting nutrients in this region for field pea production; which one of them is the most limiting is a rather circumstantial phenomenon.

Stover and grain yield contradicted in performance that could have been due to heavy rains that fell (>150-180 mm/month) during podding and grain filling stages, that caused lodging and injury of the plants including the rotting of the pods; such cases were observed more on the LTP than the upper part. Lodging is a common phenomenon that may significantly affect field pea yields [1]. However, it was not clear as to why there was more pronounced lodging on the LTP than its counterpart position. The logical explanation is that higher fertility on the former promoted more vigorous plant growth, which in turn predisposed the crop free-fall. On the other

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hand, there are also physiologically based factors that could lead to the reversed observation. For instance, imbalance in N supply in the soil in excess of a certain level tends to over-favour vegetative growth at the expense of grain production. In this connection, less of the assimilates accumulated during the vegetative phase and eventually translocated into the reproductive apparatus of the plants. In a nutshell, these observations further underscore the need for targeted soil fertility management interventions for each of the terrace position in order to optimize as well as achieve sustainable crop production. This could provide an entry point in soil management and uplift the status-quo of field pea that has had no research attention in sub-Saharan Africa.

CONCLUSION

The most constraining nutrient in the soils of SW Uganda is P; its deficiency particularly manifests in terms of the intensity of BNF indicators (nodule numbers and effectiveness, and dry weight). However, the effect of P is closely followed by and eventually surpassed that of N, especially in terms of stover and grain yield. The LTP is generally more fertile than the UTP, but the former favours stover production, while the latter favours grain yield. Heavy rains and their attendant lodging effects appear to affect grain yields on the LTP more than the upper positions. Management of highland areas characterized by bench terraces and fertility gradients need to involve strategic nutrient applications regimes based on soil tests especially for key crops like grain legumes that are widely produced by millions of smallholder farmers in Africa.

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List of abbreviations:
N-Nitrogen
P-Phosphorus
K-Potassium
Ca-Calcium
SSA-Sub-Saharan Africa
SW-Southwestern Uganda
UTP-Upper terrace position
LTP-Lower terrace position
SDW-Shoot dry weight
DAP-Days after planting
ANOVA (analysis of variance)
LSD-Least significant difference
ATP-Adenosine Tri-Phosphate
BNF- Biological Nitrogen Fixation

Table 1: Chemical characteristics of the site soil in SW Uganda

Terrace position	pH	Organic Matter	Total N	Bray 1 P	K^+	Ca^{2+}
	(%)			(mg kg^{-1})	Exchangeable (cmol. kg^{-1})	
Upper	5.2	3.8	0.21	1.76	0.61	4.96
Lower	5.3	4.4	0.27	5.84	0.66	5.84
†Critical values	**5.5**	**3**	**0.2**	**15**	**0.4**	**4.5**

†Critical values for most crops in East Africa [11]

Table 2: Shoot dry matter response to nutrient application on bench terraces at flowering

Nutrient treatments	Dry above ground matter (kg ha^{-1})	
	Upper Terrace Position	Lower Terrace Position
Control	2789	3256
N+P	5298	3654
N+K	4573	3714
P+K	4821	3147
N+P+K	4318	3961
N	5336	4538
P	3852	3531
K	4343	3940
$LSD_{0.05}$	1208	840

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